

FINAL TECHNICAL REPORT FOR NATIONAL
AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH GRANT
1982 - 1987

600-1
70-11-1
151016
p 7

GRANT TITLE: System Theory and Algorithms of
Totally Automatic Flight Control
Systems

GRANT NO: NAG2-203

GRANTEE: Texas Tech University
Lubbock, Texas 79409

PRINCIPAL
INVESTIGATOR: Renjeng Su
Department of Electrical Engineering
and Computer Science

(NASA-CR-192769) SYSTEM THEORY AND
ALGORITHMS OF TOTALLY AUTOMATIC
FLIGHT CONTROL SYSTEMS Final
Technical Report, 1982 - 1987
(Texas Technological Univ.) 7 p

N93-71772

Unclas

29/08 0154210

To CASI

In conducting the research funded by NASA research grant entitled "System Theory and Algorithms of Totally Automatic Flight Control Systems", our goals are

- (i) to develop a theoretical foundation for the Totally Automatic Flight Control Systems (TAF COS) which are conceived and researched by Dr. George Meyer and his colleagues at NASA/Ames Research Center.
- (ii) to devise computational algorithms necessary to realize this design methodology.
- (iii) to develop on the basis of TAF COS a conceptual framework which is suitable for synthesis of higher-level intelligent control.

Our research findings made during the period from 1982 to 1987 are documented in various publications. A list of the publications is attached to this report. We briefly summarize our results and the state of our thinking in the following.

In view of the fact that a majority of control theories deals with regulation problems, TAF COS presents a unique approach to the control problem of global and transient behavior of a system.

The approach is a sound one in that it explicitly separates the function of regulation and that of global and transient command generation. From this two-level controller design, one should realize the formation of a control hierarchy. It is natural that further high-level controllers are built to increase the over-all intelligence of the plant/controller combination. In doing so, a controller is no longer a mere augmentation or compensation of the controlled plant. It will become an intelligent unit which can handle many functions such as task planning,

logic decision making, resource allocation, dynamic path generation, and regulation. As the control system grows into such a sophisticated unit, the plant becomes increasingly a physical effector which merely executes the decision made by the controller.

The higher the control level is in the generalized TAF COS structure, the more global problems it handles, and hence, the more nonlinear the dynamics becomes. The command generator in the existing TAF COS design fits into this framework. In order to generate a piece of path command which extends over a substantial period of time, the underlying aircraft dynamics is inevitably nonlinear. The TAF COS design gets around the nonlinear problem by synthesizing dynamic path with a set of kinematic variables which are related by a linear dynamic model.

This unique approach has been established on a vigorous mathematical foundation, which is called feedback linearization theory. In general, application of feedback linearization requires decision of linear canonical models and solution of a set ordinary differential equation. A few solution algorithms have also been devised for such purposes. These results are contained in the papers in the publication list.

The transformation handles the so called "soft nonlinearities". The "hard nonlinearities" such as signal limitations (resource limitation) are yet to be dealt with for the problem of path generation to be solved in a more complete sense. How to dynamically allocate the limited control power between the command generation and regulation is still an open problem.

Dynamic paths must not only be generated on the basis of the more discrete commands passed down from the controller one level higher, but also take into consideration environment factors. Relatively speaking,

short-lived disturbances are better handled by the low-level regulation controller (e.g. using bandwidth to block out the disturbances) and persistent disturbances such as constant winds are best considered in the command generation.

In this exact sense, the command generator is also a feedback controller, although the feedback signals are different from that to the regulator. Another significant fact is that the command generator is designed on the plant/regulator combination, but not on the controlled plant alone.

To generalize this design situation, controller at each level is designed on the model of its underlying plant/controllers combination. Higher-level controllers deal with dynamics of longer time horizon, and its feedback signals cover more global information and are in a more condensed and discrete form.

When a decision is made by a controller at a certain level and is well executed by the lower system complex, the controller acts like an open loop controller. However, if we imposed the assumption that each lower complex successfully executes the decision from immediate upper controller we would have cancelled the crucial problem of interaction between controllers at various levels. More importantly, for real-time applications such as aircraft control, the interaction seems to be a necessity and therefore, must be dealt with from the outset in the modelling process.

To sum up, we feel that the transformation theory associated with TAF COS is now more or less complete. The combination of command generator and regulator, however, only represents an embryo of a much more global controller complex. It is important to pursue this line of

research further, both in experimental design and in modelling and analysis. Results of such research will bring out real use of modern digital computers and put human operators of such control system in a position of handling more global decision making.

List of Publications

I. Refereed Journal Papers:

- (1) "Observability of two dimensional systems," Mathematical System Theory, Vol. 17, pp. 159-166, 1984, with L.R. Hunt.
- (2) "A simple algorithm for computing canonical forms," accepted by the international Journal of Computers and Mathematics with Applications, with H. Ford and L.R. Hunt.
- (3) "Application of nonlinear transformations to automatic flight control," Automatica, Vol. 20, No. 1, pp. 103-107, 1984, with G. Meyer and L.R. Hunt.
- (4) "Exact linearizations of input-output systems," International Journal of Control, Vol. 43, No. 1, pp. 247-255, 1986, with L.R. Hunt and M. Luksic.
- (5) "A canonical form for nonlinear systems," IEEE Trans. AC, Vol. 31, No. 7, pp. 670-673, 1986, with L.R. Hunt.
- (6) "Approximation of nonlinear systems having outputs," Circuits Systems Signal Process, Vol. 5, No. 4, 1986, with L.R. Hunt.
- (7) "Approximating linearization for nonlinear systems," Circuits Systems Signals Process, Vol. 5, No. 4, 1986, with L.R. Hunt and G. Meyer.

II. Conference Papers:

- (1) "Applications to aeronautics of the theory of transformations of nonlinear systems," CNRS conference, to appear with G. Meyer and L.R. Hunt.
- (2) "A natural coordinate system for nonlinear systems" 22nd IEEE Conference on Decision and Control, 1983.

- (3) "A separation principal for automatic systems design," to appear in the Proceedings of Ames-Berkeley Conference on Nonlinear Dynamics and Control, 1984.
- (4) "Nonlinear Designs for Command Generation," 24th IEEE Conference on Decision and Control, 1985.
- (5) "A tuning scheme for proportional-and-derivative controllers," to be presented in 1987 IEEE Conference on Decision and Control.